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ON TRIBOLOGICAL BEHAVIOR OF SYNTHETIC FIBER REINFORCED POLYMER COMPOSITES MODIFIED WITH FILLERS: A REVIEW

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ABSTRACT

Polymer composites reinforced with fibers have been consistently employed in applications involving friction in many industrial components. Though natural fibers possess many advantages, they absorb greater moisture and also their impact properties being quite low, ultimately degrades the mechanical properties. On the other hand, synthetic fibers offer greater specific strength, less density and extraordinary mechanical and tribological properties and hence substituted with many natural fibers. In this point of view, an effort has been made in this article to highlight the tribological behavior of a number of synthetic fiber reinforced polymer matrix composites modified by fillers to satisfy greater strength or modulus requirements.

KEYWORDS: Synthetic Fiber, Polymer Resin, Tribological Behavior & Fillers

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Original Article

INTRODUCTION

Since the past few decades, there has been a growing demand for materials which are stronger as well as stiffer, but at the same time lighter, used in different fields like aerospace, energy and civil constructions. With regard to this requirement and due to an unparalleled quest for newer materials, composite materials evolved, which has proven to be a massive breakthrough in the relentless effort of optimization in materials.

Typically, a composite material constitutes two or more materials which are mixed and bonded on a macroscopic scale [1]. Any composite material is made up of three main elements-the matrix, the reinforcement or fiber, and the so-called interfacial region. Reinforcing fibers provide strength and hardness to the composite, while the matrix materials provide corrosion resistance, toughness and ductility. Literature reveal that, along with fiber and matrix material, one or more forms of filler materials or additives have been added to suit greater strength and modulus requirements [2]. The interfacial region is accountable for the communication amongst the matrix and filler material and is usually recognised with properties dissimilar to that of the matrix owing to its immediate vicinity to the surface of the filler.

The fibers used in composites may be either natural or synthetic, while the matrix may be a metal, ceramic or a polymer. Natural fibers demonstrate reduced impact strength and increased moisture absorption which results in degradation of mechanical properties [3]. Furthermore, the use of natural fibers is limited to only non-tribological applications as they possess strength values lower than that of polymer composites prepared by reinforcing synthetic fibers. Incidentally, the synthetic fibers also exhibit low density, high specific strength and exceptional mechanical properties. On the other hand, polymers offer advantages like low density, decent corrosion resistance, low thermal and electrical conductivity, translucence, aesthetic colour effects etc. Polymer matrix composites are being

extensively used in the field of friction and wear because of their lightweight, high strength, abrasion resistance and high load carrying capacity. Since the polymer matrix essentially needs to resist higher loads, it is normally reinforced with fibers and fillers. Polymer composites reinforced with synthetic fibers made up of glass [4–20], carbon [21–30], aramid [31–34] etc. are being extensively deployed in engineering applications because of their exceptional mechanical performance. The detailed classification of synthetic fibers is illustrated in Figure 1.

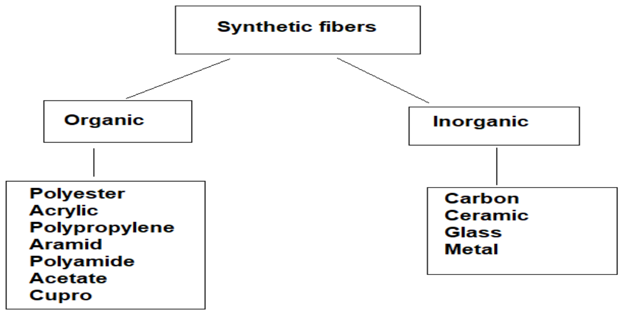

Figure 1: Commonly Used Organic and Inorganic Synthetic Fibers

TRIBOLOGY AND ITS NEED

Tribology deals with the study and application of the principles of friction and lubrication concerning two surfaces that interact and are in relative motion. Since the failures associated with wear and friction can incur a heavy cost to any industry and also may lead to its shutdown, the analysis of tribological behavior becomes extremely important. Characteristic tribological properties like self-lubrication, lower friction coefficient and superior wear resistance are anticipated in machine parts such as gears, cams, wheels, brakes, bearings, bushings[35] and so on. Polymers with fibers and fillers are widely used in order to achieve this objective.

HYBRID POLYMER COMPOSITES

Hybrid polymer composites are novel and advanced composites when compared to conventional polymer composites reinforced with fibers. A fiber-reinforced composite comprises of only a single reinforcing phase in a single matrix, whereas hybrids could possess more than one phase of reinforcement with a single matrix or one phase of reinforcement with several phases of matrix materials. The usage of natural fibers leads to adverse mechanical and electrical properties as a result of the mismatch with the hydrophobic polymer matrix. These limitations can be reduced by hybridization technique [36]. Friction and wear rate is typically affected by the properties of matrix and reinforcement materials, process opted for manufacturing, orientation and length of the fibers, conditions under which the components are operated as well as the sequence of stacking of the laminates. Therefore, the parameters like sliding distance and load applied are optimised to improve the wear properties [37].

LITERATURE REVIEW

Baptista et al. (2016) explored the influence of varying amounts of graphite filler content on the mechanical as well as tribological properties of epoxy composites reinforced with carbon fibers. Epoxy matrix composites comprising 0 to 30 wt.% graphite were prepared. The prepared composite samples were characterized for their mechanical properties and resistance to sliding wear. The results showed that the existence of graphite in the matrix material ultimately increased the wear resistance due to the lubricant action exhibited by graphite.

Srinivas and Bhagyashekar (2014) studied the tribological behavior of composites reinforced with graphite and silicon carbide (SiC) particulates with epoxy as the matrix material and a hybrid Graphite-SiC as filler. The results showed that the hybrid filler improved the wear resistance when compared with that of Graphite-SiC.

Zhang et al. (2014) prepared carbon fabric reinforced phenolic matrix composites modified with potassium titanate whiskers (PTW) as the fillers and the tribological properties of the prepared composites were studied. The results showed that the optimal PTW considerably reduced the wear rate. It was observed that the sliding conditions highly influenced the friction and wear properties of the composites.

B. Suresha et al. (2018) fabricated carbon fiber mat reinforced epoxy matrix composite with varying amounts of PT Was filler material. The influence of PTW on the wear behaviour under dry sliding conditions of the fabricated composite was examined. The results indicated that the integration of PTW into the composite improved the resistance to wear.

M. Sudheer et al. (2014) developed composites reinforced with E-glass fiber and epoxy matrix, while PTW and graphite were used as fillers and solid lubricant respectively. The effect of PTW and graphite on the dry sliding wear behaviour of the composites were studied. The experimental results showed that the single combination of PTW filler improved the friction coefficient of the composites.

Li et al. (2016) inspected the tribological performance of kevlar fabric reinforced polytetrafluoroethylene(PTFE) matrix composites with SiC and tungsten disulphide (WS_2) as filler materials. The results indicated that the hybrid fillers filled composites attained the anticipated tribological properties in dry sliding which could be attributed to the development of a stable transfer film against the counter surface.

Wei et al. (2018) prepared a carbon fabric reinforced epoxy matrix composite. The filler material being, six potassium titanate whisker (SPTW). Investigations were carried out to assess the changes in friction and wear of the composite with different loads and to understand the effect of fillers on its tribological properties. The results revealed that the SPTW exerted a good wear resistance effect.

Basavarajappa and Ellangovan (2012) fabricated an E-glass fiber reinforced epoxy composite with SiC and graphite particles as fillers. The selection of these materials as fillers was because of the fact that they have the capacity to withstand high temperature. The composites prepared were tested for their dry sliding wear characteristics. It was observed that the incorporation of fillers to the composite resulted in improved wear resistance.

The abrasive wear performance of glass epoxy composites with granite as fillers were investigated by S Basavarajappa et al. (2011) using structural analysis. The specimens were prepared by hand layup method and were abraded against a silicon carbide particle (SiCp) abrasive paper. The results revealed that the addition of granite as secondary reinforcement increased the resistance to abrasive wear of the composite specimen. In addition, it was realised that the load applied and sliding distance was the significant physical and statistical parameter that influenced the wear of the composite.

Bhagyashekar and Rao (2007) performed a study on analysing the effect of wear behaviour of particulate filled SiC-epoxy and graphite-epoxy composites using a pin on disc arrangement. The results indicated that the addition of fillers with epoxy increased the wear resistance, in particular the graphite epoxy composite.

Suresha et al. (2007) inspected the friction and wear behavior of glass-epoxy composites with SiC and graphite as fillers. It was revealed that, upon addition of graphite and SiC particulate as fillers the friction and wear of the composite was considerably reduced. In other words, the glass-epoxy composite filled with SiC gave better resistance to sliding wear when compared to glass-epoxy composites which were unfilled.

A. A. Megahed et al. (2017) studied the tribological performance of composites reinforced with woven tissue glass fiber in an epoxy matrix with silica and carbon nano particles as fillers. The results obtained from wear test indicated that the integration of silica and carbon nano particles considerably enhanced the resistance to wear. The analysis of variance (ANOVA) results revealed that time was the highly influencing parameter.

W. Sun et al. (2018) prepared kevlar fabric reinforced PTFE matrix composite with milled pitch based carbon fibers (CF) as fillers and investigated the tribological properties. These are a class of self-lubricating materials used in bearing liners. The results demonstrated that the suitable combination of CF could reduce the wear rate of the composite with virtually fixed value of friction coefficient.

N. Dadkar et al. (2009) fabricated fly ash filled kevlar pulp reinforced phenolic resin composite and investigated the tribological properties for friction braking applications. The wear test results exhibited decrease in the friction fade behaviour of the composite with fly ash content, while there was a decrease observed in frictional fluctuation with the increase in flyash content.

The extensive literature review conducted to understand the tribological behavior of polymer matrix composites reinforced with synthetic fibers and modified by fillers is presented in Table 1.

Table 1: Comparison of Tribological Test Results of Various Synthetic Fiber Reinforced Polymer Matrix Composites

Type of synthetic Reinforcement	Polymer Matrix Resin	Additives/ Fillers	Hardener/ Solvent	Tribology Test Results	Reference
Woven carbon fibers fabric	Epoxy resin SR1500	Synthetic graphite platelets	SD2505	Presence of fillers decreased the subsurface fatigue wear	[38]
Silicon carbide and Graphite	Epoxy resin LY556	Hybrid graphite-SiC	Amine hardener HY951	Hybrid filler improved the wear resistance	[39]
Plain PAN carbon fabric	Adhesive 204 phenolic resin	PTW	Mixed acetone solvent	PTW reduced the wear rate	[40]
E-glass fibers (plain woven fabric type)	Epoxy resin LY556	PTW and lubricant filler graphite	Amino based hardener HY951	Single inclusion of PTW improved anti-wear abilities	[42]
Carbon fabric	Epoxy resin E-44	Potassium hexa-titanate whiskers	Silane Coupling Agent KH550	The addition of whiskers exerted good wear resistance	[44]
E-glass fiber	Epoxy resin LAPOX L-12	SiC_p and Graphite powders	Polyamine hardener K-6	Fillers resulted in improved wear resistance	[45]
E-glass fabric	Epoxy resin LAPOX L-12	Granite particles	Polyamine hardener K-6	Addition of granite increased the abrasive wear resistance	[46]
E-glass fibers	Epoxy resin LAPOX L-12	Graphite and SiC particles	Polyamine hardener K-6	Friction and wear of the composite was considerably reduced	[48]

Table 1: Contd.,					
Kevlar fabric	PTFE	Milled pitch-based CF	-------	CF reduced the wear rate of the composites	[50]
Kevlar pulp	Phenolic resin Novolac JA 10	Flyash	-------	The fade coefficient was the deciding factor in determining the wear behaviour	[51]

CONCLUSIONS AND FUTURE SCOPE

In this review paper, an attempt has been made to study the tribological behaviour of different polymer matrices reinforced with synthetic fibers modified with filler materials. Some of the salient observations made from the literature review with respect to the choice of reinforcement, matrix and filler materials are as follows:

- E-glass is the most commonly employed material as synthetic reinforcement, while SiC and PTW are found to be the ideal filler materials used for most of the synthetic fiber polymer matrix combination intended to be used in tribological applications.
- Epoxy resin is an excellent thermosetting polymer and presents a greater adhesion to natural/synthetic reinforcements as well as organic/inorganic fillers due to the generation of a chemical bond which acts as a protective coating. However, pure epoxy is brittle and offers a lower wear resistance than its counterparts. Consequently, it becomes unfit to be used in extreme conditions. For this reason, a lot of researchers have compounded epoxy with other materials to attain better wear resistance.

The conclusions drawn from this review are summarized as follows:

- The coefficient of friction generally shows a decreasing trend with the increase in the filler content due to the formation of a thin layer between the surface of the specimen and the wear test pin thereby acting as a lubricant.
- Besides the number of filler materials added, the sliding conditions like the velocity of sliding, sliding distance and normal load applied also contribute significantly to the friction coefficient and wear properties of the polymer composite.
- For tribological applications, polymer composites offering increased resistance to wear and reduced friction coefficient are favourable.
- Some of the polymer composite properties get deteriorated with the increase in filler content. The need of the hour is to monitor the quantity of filler material being added to the composite.
- In comparison with the polymer composites prepared without filler materials, the filled composites exhibit superior wear properties owing to the fact that the fillers in the matrix enhances the thermal conductivity and thereby the frictional heat is easily transferred at the interface.
- The influence of sliding speed on the friction and dry sliding wear behaviour of polymers is dependent on the roughness of mating surfaces and does not necessarily follow the trend of higher wear rate for higher sliding speed.

- For a given volume, the whiskers which are short and fiber shaped large aspect ratio crystals, provide more surface area for interaction and increase the interface for the transfer of load. However, the literature review reported only a few studies conducted on synthetic fiber reinforced polymer matrix composite using whiskers as fillers.

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